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Angular correlation measurements on Xe^{128}

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With 5 figures in the text

ABSTRACT

The gamma-gamma angular correlation of the two cascaded gamma radiations with energies 0.540 Mev and 0.455 Mev following the negatron decay of I^{128} has been studied. The spin sequence of the Xe^{128} states is shown to be $2+\xrightarrow[M1+E2]{0.540\text{ Mev}} 2+\xrightarrow[E2]{0.455\text{ Mev}} 0+$ with 2.4 percent Ml in the 0.540 Mev transition.

There is a weak indication of positrons of an intensity of only 0.002 percent in the $I^{128}-Te^{128}$ branch.

Introduction

The iodine isotope of mass number 128 has been found to decay with a half life of 25 minutes (1) partly by negatron emission to Xe^{128} and partly by electron capture to Te^{128} (2). The disintegration scheme proposed by Benczer *et al.* (2) is shown in Fig. 1. Two gamma rays with the energies of 0.540 Mev and 0.455 Mev are found to be in cascade. A rather weak crossover of 0.99 Mev energy has also been detected.

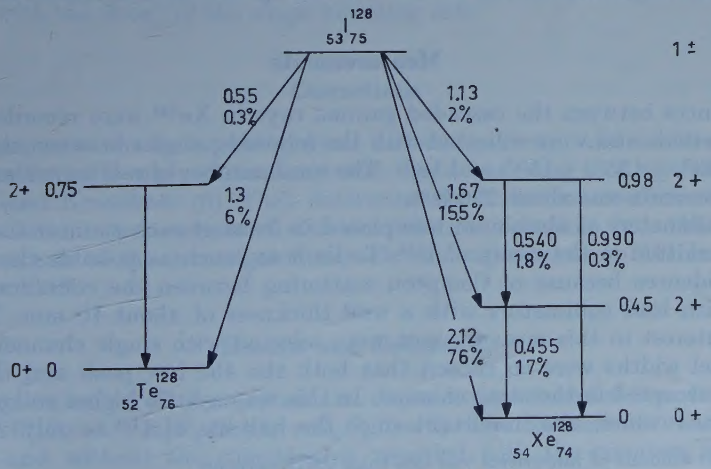

Fig. 1. Decay scheme of I^{128} (2).

Since Xe^{128} is an even-even nucleus the ground state has zero spin and even parity. The first excited state is suggested to be 2+ as is the case in almost all even-even nuclei, and the second excited state probably has the spin 2+ also. In the branch leading to Te^{128} only one gamma transition with an energy of 0.750 Mev has been reported. The spins of the ground state and the first excited state are for the same reason as above supposed to be 0+ and 2+ respectively. The negatron branch is the most populated one. The three negatron components have the energies 2.120 Mev (76 %), 1.665 Mev (15.5 %), and 1.125 Mev (2 %).

Source

I^{128} was produced by neutron irradiation of I_2O_5[1] for about 90 minutes in a reactor[2] at a neutron flux of $6 \cdot 10^{11}$ neutrons/cm² sec. The total number of irradiations was about fifty. No chemical separations were performed. The correlation measurements were made with cylindrical sources one millimeter in diameter. The source containers were made of aluminum with a wall thickness of 0.1 mm. The sources varied in length between one and five millimeters. By using small sources and thin sample holders smearing out effects on the anisotropy were kept negligible. The number of sources used was more than 170 in all. The life-time of the first excited state theoretically calculated to be about $4 \cdot 10^{-10}$ seconds (3) (probably it is even shorter) is short enough to permit measurements with a polycrystalline source without attenuation of the anisotropy.

Apparatus

The apparatus has been described earlier (4). However, some modifications were introduced. To be able to get a simpler and faster coincidence circuit the photomultiplier (RCA 6342) voltages were raised to about 1800 volts. Accordingly, the anode pulses of the multipliers were large enough for most gamma ray energies to cut off a suitably biased 404A pentode. After the 404A limiter the pulses were clipped with a RG 114/U shorted stub and fed to a crystal diode coincidence arrangement (5). The stub length was so chosen that a resolving time of 12 millimicroseconds was obtained.

Measurements

Coincidences between the cascaded gamma rays in Xe^{128} were recorded during 4 minute intervals and were collected with the following angles between the counters: ±90°, ±120°, ±135°, ±150°, and 180°. The total number of real coincidences during the measurements was about 230 000.

Three millimeters of aluminum was placed in front of each counter to absorb the beta rays emitted in the decay of I^{128}. To limit as much as possible the number of false coincidences because of Compton scattering between the counters these were shielded with lead collimators with a wall thickness of about 10 mm. The photopeaks of interest in this measurement were selected with single channel analyzers. The channel widths were so chosen that both the 455 kev peak and the 540 kev peak were accepted in the same channel. In this way a little higher coincidence rate was obtained which was important since the half-life of I^{128} is only 25 minutes.

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[1] The total amount of impurities was less than 0.075 percent.

[2] The reactor type R1 of AB Atomenergi, Stockholm, Sweden.

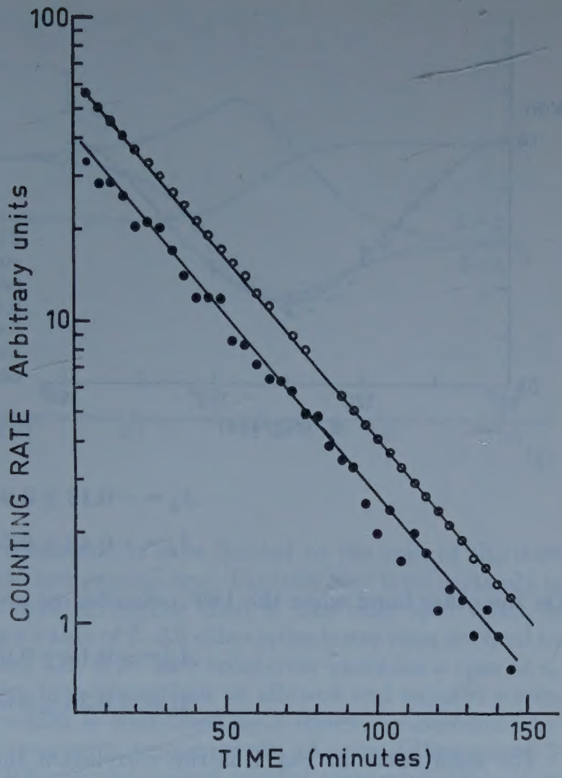

Fig. 2. Decay curves of the iodine samples. Open dots represent the channel rate and filled dots the coincidence rate.

By following the coincidence rate continuously for two hours with an angle of 180° between the counters it was found that the sources did not contain any long lived positron emitting activities. Fig. 2 shows the decay curve of the 180° coincidences compared with the decay of the single counting rate.

Corrections

Corrections were made for background radiation, decay, and accidental coincidences. Counter solid angle corrections were made according to a method proposed by Church and Kraushaar (6). They determine the correction coefficients from the angular resolution curve measured with annihilation radiation. It is thus necessary that the energies of the investigated cascade are rather close to 511 kev which is the case for Xe^{128}.

Results and discussion

After application of all corrections the experimental material was fitted to the expression $W(\theta) = 1 + A_2P_2(\cos\theta) + A_4P_4(\cos\theta)$. The coefficients were computed both with and without the coincidences recorded with the counters in the 180° position. With these coincidences taken into account the coefficients are

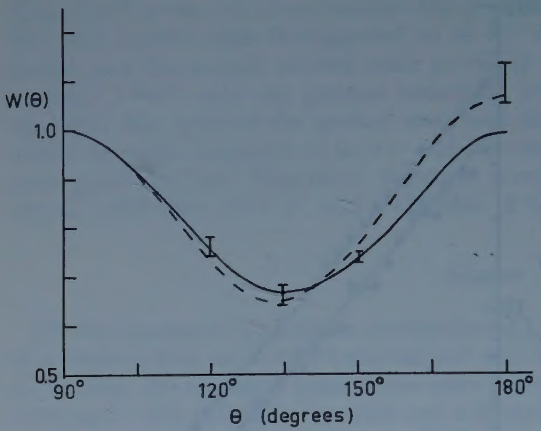

Fig. 3. Experimental angular correlation curves. The dotted curve shows the correlation obtained for $A_2 = -0.13$ and $A_4 = 0.43$ and the solid curve the distribution for $A_2 = -0.18$ and $A_4 = 0.35$. The experimental 180°-value is omitted in the last case.

$$A_2 = -0.13 \pm 0.04$$

$$A_4 = +0.43 \pm 0.05.$$

On the other hand when the 180° coincidences are omitted the coefficients are

$$A_2 = -0.18 \pm 0.02$$

$$A_4 = +0.35 \pm 0.04.$$

The solid curve in Fig. 3 is the correlation function drawn for $A_2 = -0.18$ and $A_4 = 0.35$ and the dotted curve is for $A_2 = -0.13$ and $A_4 = 0.43$. As the difference between the two curves is due to the omission or addition of the 180° experimental point and since the dotted curve has a higher $W(180°)$ value than the solid curve the difference could be explained by coincidences caused by annihilation radiation from positrons emitted by I^{128} or any contaminating positron emitting isotope. Fig. 2, however, shows that the sources were probably free from disturbing activities. Accordingly it cannot be excluded that I^{128} emits a few positrons and that their annihilation radiation is registered since the settings of the single channel analyzer positions are defined in relation to the 455 kev and 540 kev gamma lines. The detection of the 511 kev annihilation quanta results in an increased coincidence rate in the 180° counter position. These arguments are slightly strengthened by the fact that the dotted curve of Fig. 3 does not fit the experimental points as well as the solid curve. The number of positrons can be only 0.002 percent of the iodine decays. No gamma line of an energy larger than 1.02 Mev is known in the decay of I^{128} and internal or external pair creation is thus not possible. Barber (7) has investigated the beta decay as to positrons and has found the positron to electron emission ratio to be less than 0.002.

Theoretical A_2 and A_4 values in the Legendre expansion $W(\theta) = 1 + A_2P_2(\cos\,\theta) + A_4P_4(\cos\theta)$ are given for different spin values by Ferentz and Rosenzweig (8).

The gamma transition is assumed to be pure $E2$ between a first excited spin $2+$ state and a $0+$ ground state in even-even nuclei. Since Te^{128} has an even number of both neutrons and protons the 455 kev ground state transition is also probably an

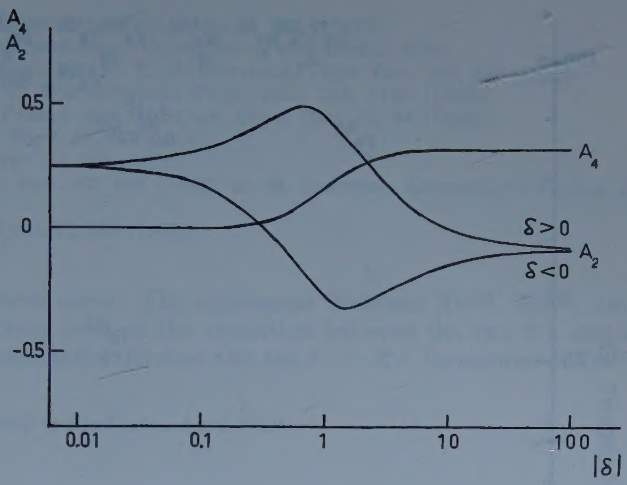

Fig. 4. A_2 and A_4 as functions of the mixing parameter δ for the spin sequence 2–2–0.

electric quadrupole. The following discussion is thus limited to the spin of the 0.98 Mev level and the character of the 540 kev gamma line. The 0.98 Mev level certainly is a second excited state having a spin no higher than 4. The only spin which is compatible with the experiment has a value of 2. All other spins lower than or equal to 4 are also excluded for other reasons. The 0.98 Mev cross-over excludes a spin of 4. The log *ft* values seem to classify the beta-transitions as allowed and support a spin of 1 of the groundstate of I^{128} (2) which is confirmed by a direct measurement by use of the atomic beam magnetic resonance technique (9). A spin difference of 3 units between the ground state of I^{128} and the second excited state of Xe^{128} is thus not possible and the spin 4 of the state is discarded. The cross-over seems to have too high an intensity to allow spin 3 of the second level in accordance with the correlation results. The spins 1 and 0 are definitely ruled out by the correlation measurement. The spins discussed are definitely ruled out by the correlation measurement whether the 540 kev transition is mixed or not.

In the case of the spin sequence $2 \rightarrow 2 \rightarrow 0$ the coefficients of the Legendre polynomial can be written

$$A_2 = \frac{0.2500 + 2\delta \cdot 0.3660 - \delta^2 \cdot 0.0766}{1+\delta^2} \quad \text{and} \quad A_4 = \frac{0.3265\,\delta^2}{1+\delta^2}$$

where $\delta^2 = E2/M1$ of the $2 \rightarrow 2$ transition. Fig. 4 shows A_2 and A_4 as functions of δ. The experimental values $A_2 = -0.18$ and $A_4 = 0.35$ fit the curves rather well, giving $\delta = -6.4 \pm 1.5$ which means that the 540 kev transition consists of 2.4 percent of $M1$. The spin 2 of the second excited state is in agreement with earlier proposals (2, 10).

It is interesting to study the percentage of $E2$ of the transition between two 2+ states. Fig. 5 shows the amount of $E2$ plotted as a function of the neutron number of some even-even nuclei. Included is Xe^{128} and also Te^{126} and Xe^{126} which are being investigated in this laboratory at present (11). It is seen that in regions well apart from closed shells the transitions are of almost pure $E2$ type. At magic numbers,

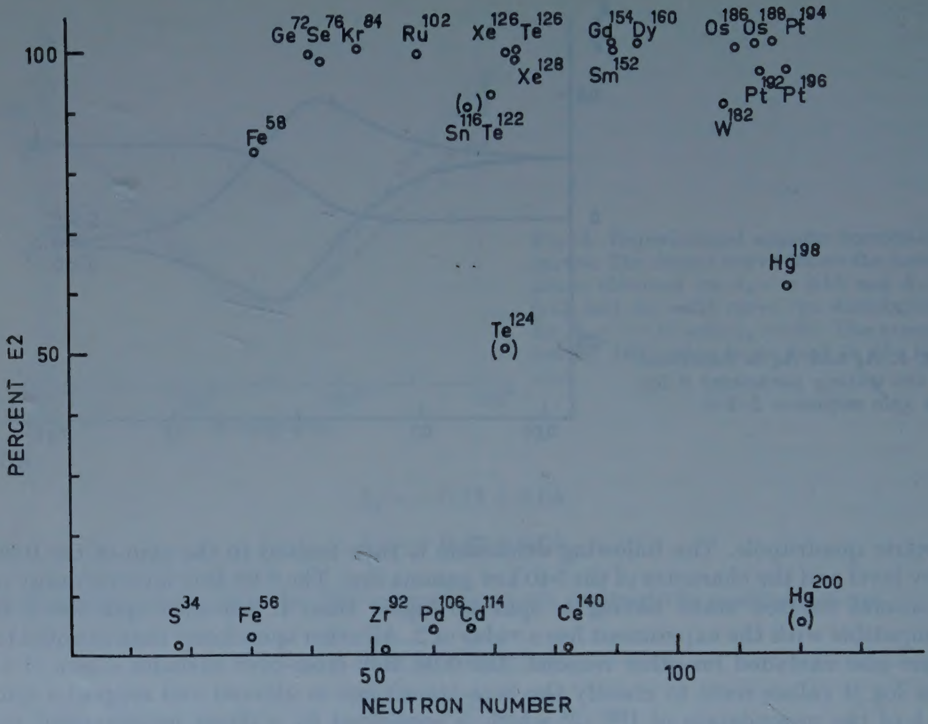

Fig. 5. Percentage E2 radiation in some 2+–2+ transitions as a function of the neutron number N. Dots in brackets are uncertain.

S^{34}:	H. E. HANDLER and J. R. RICHARDSON, Phys. Rev. *102*, 833 (1956).
Fe^{56}:	P. DAGLEY, M. A. GRACE, J. M. GREGORY, and J. S. HILL, Proc. Roy. Soc. A *250*, 550 (1959).
Fe^{58}:	H. FRAUENFELDER, N. LEVINE, A. ROSSI, and S. SINGER, Phys. Rev. *103*, 352 (1956).
Ge^{72}:	R. G. ARNS and M. L. WIEDENBECK, Phys. Rev. *112*, 229 (1958).
Se^{76}:	T. LINDQVIST and I. MARKLUND, Nucl. Phys. *4*, 189 (1957).
Kr^{84}:	N. R. JOHNSON and G. D. O'KELLEY, Phys. Rev. *108*, 82 (1957).
Zr^{92}:	C. F. COLEMAN, Nucl. Phys. *7*, 488 (1958); H. I. WEST, JR., L. G. MANN, and G. M. IDDINGS, Phys. Rev. Letters *2*, 139 (1959).
Ru^{102}:	K. HISATAKE and J. D. KURBATOV, Bull. Am. Phys. Soc. *3*, 315 (1958).
Pd^{106}:	E. D. KLEMA and F. K. MCGOWAN, Phys. Rev. *92*, 1469 (1953).
Cd^{114}:	S. C. DAUBIN and D. R. HAMILTON, Phys. Rev. *99*, 683 (1955).
Sn^{116}:	R. P. SCHARENBERG, M. G. STEWART, and M. L. WIEDENBECK, Phys. Rev. *101*, 689 (1956).
Te^{122}:	T. LINDQVIST and I. MARKLUND, Nucl. Phys. *4*, 189 (1957); M. J. GLAUBMAN, Phys. Rev. *98*, 645 (1955); C. F. COLEMAN, Nucl. Phys. *7*, 488 (1958).
Te^{124}:	T. LINDQVIST and I. MARKLUND, Nucl. Phys. *4*, 189 (1957).
Te^{126}: Xe^{126}:	L. G. STRÖMBERG, I. ASPLUND, and T. WIEDLING. To be published.
Xe^{128}	Present work.
Ce^{140}:	C. F. COLEMAN, Phil. Mag. *46*, 1132 (1955).
Sm^{152}:	S. OFER, Nucl. Phys. *4*, 477 (1957).
Gd^{154}:	D. G. HICKMAN and M. L. WIEDENBECK, Phys. Rev. *111*, 539 (1958).
Dy^{160}:	S. OFER, Nucl. Phys. *5*, 331 (1957).
W^{182}:	R. C. WILLIAMS and K. I. ROULSTON, Canad. J. Phys. *34*, 1087 (1956).

Os^{186}:	T. Lindqvist and I. Marklund, Nucl. Phys. *4*, 189 (1957).
Os^{188}:	T. Wiedling, Doctoral dissertation, University of Stockholm, 1956; V. R. Potnis, V. S. Dubey, and C. E. Mandeville, Phys. Rev. *102*, 459 (1956).
Pt^{192}:	W. H. Kelly and M. L. Wiedenbeck, Phys. Rev. *102*, 1130 (1956).
Pt^{194}:	C. E. Mandeville, J. Varma, and B. Saraf, Phys. Rev. *98*, 94 (1955).
Pt^{196}:	V. R. Potnis, Indian J. Phys. *30*, 375 (1956); R. M. Steffen, Phys. Rev. *89*, 665 (1953).
Hg^{198}:	C. D. Schrader, Phys. Rev. *92*, 928 (1953); R. M. Steffen, Advances in Physics *4*, 293 (1955).
Hg^{200}:	T. Lindqvist, Arkiv f. Fysik *12*, 495 (1957).

however, small $E2$ admixtures occur. The agreement between Te^{126}, Xe^{126}, and Xe^{128} is remarkable. The mixing ratio of the transition between the two $2+$ states of Sn^{116} seems to need a reexamination as does also the $2+ - 2+$ transitions of Te^{124}, and Hg^{200}.

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REFERENCES

1. D. E. Hull and H. Seelig, Phys. Rev. *60*, 553 (1941).
2. N. Benczer, B. Farrelly, L. Koerts, and C. S. Wu, Phys. Rev. *101*, 1027 (1956).
3. S. A. Moszkowski, Beta and Gamma Ray Spectroscopy, Chapter XIII, p. 373 (edited by K. Siegbahn, North-Holland Publ. Co., Amsterdam, 1955).
4. T. Wiedling, Thesis, Stockholm 1956.
5. R. E. Bell, R. L. Graham, and H. E. Petch, Canad. J. Phys. *30*, 35 (1952).
6. E. L. Church and J. J. Kraushaar, Phys. Rev. *88*, 419 (1952).
7. W. C. Barber, Phys. Rev. *72*, 1156 (1957).
8. M. Ferentz and N. Rosenzweig, Table of F Coefficients (ANL-5324).
9. J. E. Sherwood, Bull. Am. Phys. Soc. Ser. *II, 2,* 344 (1957).
10. H. Bosch, R. Radicella, P. Reyes, and T. Urstein, Phys. Rev. *111*, 898 (1958).
11. L. G. Strömberg, I. Asplund, and T. Wiedling. To be published.

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